Geological Survey
of Canada

Current Research
2000-E7

Preliminary results of electrical characteristics of mineralized and nonmineralized rocks from the Yellowknife area, Northwest Territories

T.J. Katsube, J. Mwenifumbo, J. Kerswill, S. Connell, and N. Scromeda

2000

Natural Resources Canada Ressources naturelles Canada

Canada

100-06731/

©Her Majesty the Queen in Right of Canada, 2000
Catalogue No. M44-2000/E7E-IN
ISBN 0-660-18211-4

Available in Canada from the
Geological Survey of Canada Bookstore website at:
http://www.nrcan.gc.ca/gsc/bookstore (Toll-free: 1-888-252-4301)

A copy of this publication is also available for reference by depository libraries across Canada through access to the Depository Services Program's website at http://dsp-psd.pwgsc.gc.ca

Price subject to change without notice

All requests for permission to reproduce this work, in whole or in part, for purposes of commercial use, resale or redistribution shall be addressed to: Geoscience Information Division, Room 200, 601 Booth Street, Ottawa, Ontario K1A 0E8.

Authors' address

T.J. Katsube *(jkatsube@nrcan.gc.ca)*
J. Mwenifumbo *(jarako@nrcan.gc.ca)*
J. Kerswill *(jkerswil@nrcan.gc.ca)*
S. Connell *(sconnell@nrcan.gc.ca)*
N. Scromeda *(nperez@nrcan.gc.ca)*
Mineral Resources Division
Geological Survey of Canada
601 Booth Street
Ottawa, Ontario K1A 0E8

Preliminary results of electrical characteristics of mineralized and nonmineralized rocks from the Yellowknife area, Northwest Territories[1]

T.J. Katsube, J. Mwenifumbo, J. Kerswill, S. Connell, and N. Scromeda
Mineral Resources Division, Ottawa

Katsube, T.J. Mwenifumbo, J. Kerswill, J., Connell, S., and Scromeda, N., 2000: Preliminary results of electrical characteristics of mineralized and nonmineralized rocks from the Yellowknife area, Northwest Territories; Geological Survey of Canada, Current Research 2000-E7; 6 p. (online; http://www.nrcan.gc.ca/gsc/bookstore)

Abstract: Electrical resistivity characteristics of a suite of ten rock samples from the Giant and Con mines (Northwest Territories) have been investigated to provide information for development of exploration strategies and to aid interpretation of down-hole, ground, and airborne electromagnetic (EM) surveys. Samples include material from 1) gold-bearing quartz veins; from altered shear zones represented by 2) sericite schist immediately adjacent, and 3) chlorite schist further removed from these veins; and from 4) basalt that hosts the shears and veins.

Preliminary results indicate that nonmineralized rocks display electrical resistivity (ρ_r) values of 2000–24 000 Ω·m with weak electrical anisotropy (4:1–7:1). Some sections of the gold-bearing vein display low ρ_r values (30–100 Ω·m), but without evidence of continuity. Mineralized sericite schist displays intermediate ρ_r values (600–1000 Ω·m) and with continuity along foliation with relatively strong anisotropy (10:1), implying that it might form a good exploration target; however, inappropriate survey-line orientation could cause EM surveys to miss the target, due to the electrical anisotropy.

Résumé : Les caractéristiques de résistivité électrique d'un ensemble de dix échantillons de roches provenant des mines Giant et Con (Territoires du Nord-Ouest) ont été étudiées afin d'obtenir l'information nécessaire à l'élaboration de stratégies d'exploration et pour faciliter l'interprétation de levés électromagnétiques de sondage, au sol et aériens. Les échantillons consistaient en matériaux tirés 1) de filons de quartz aurifère; de zones de cisaillement altérées représentées par 2) du séricitoschiste immédiatement adjacent et 3) du chloritoschiste un peu plus loin de ces filons; et 4) de basalte encaissant les cisaillements et les filons.

Les résultats préliminaires indiquent que les roches non minéralisées présentent des valeurs de la résistivité électrique (ρ_r) de 2 000 à 24 000 Ω·m et une faible anisotropie électrique (de 4:1 à 7:1). Certains segments des filons aurifères présentent de faibles valeurs de ρ_r (de 30 à 100 Ω·m), mais aucune indication de continuité. Le séricitoschiste minéralisé présente des valeurs intermédiaires de ρ_r (de 600 à 1 000 Ω·m) et une continuité le long de la schistosité avec une anisotropie relativement forte (10:1), ce qui signifie qu'il pourrait constituer une bonne cible d'exploration. Cependant, des lignes de levés électromagnétiques mal orientées pourraient ne pas permettre la détection des cibles en raison de l'anisotropie électrique.

[1] Contribution to the 1999-2003 Yellowknife, Canada-Northwest Territories Exploration Science and Technology (EXTECH III) Initiative

INTRODUCTION

Electrical resistivity characteristics have been determined for ten mineralized and unmineralized rock samples from the Giant mine and Con mine areas (Northwest Territories) in order to provide information to help develop exploration strategies and to aid interpretation of down-hole, ground and airborne electromagnetic survey data. This is a preliminary petrophysical study, and consists of electrical resistivity and porosity measurements (Scromeda et al., 2000), analysis of electrical characteristics including electrical anisotropy analysis (Connell et al., 2000b), and electrical mechanism analysis including scanning electron microscope analysis (Connell et al.,2000a). The samples include material from 1) gold-bearing quartz veins from a mineralized shear zone; 2 sericite schist and 3) chlorite schist from alteration zones that parallel the gold-bearing vein; and 4) basalt that constitutes the barren host to the shears and veins.

Gold mineralization in this area appears to be confined to shear zones where chlorite-carbonate-sericite-sulphide-bearing schists host multiple generations of quartz-ankerite veins (McDonald et al., 1993). The mineralized and nonmineralized samples used in this study have been collected from sections that traverse the quartz-ankerite veins, sericite schist, chlorite schist and the massive basalt host rock (Fig. 1). They were mainly collected from underground sections of the Giant and Con mines (Northwest Territories). Out of the many samples that were collected, ten samples representing mineralized and nonmineralized sections of the quartz-ankerite veins, sericite schist, chlorite schist, and basalt were selected for this preliminary study. Further detailed studies are planned for the future.

The purpose of this paper is to present the analytical results obtained by this preliminary study, and to discuss their implications for development of exploration strategies and interpretation of ground and airborne electromagnetic survey data. Presentation of the data follow description of the sampling strategy and a brief description of the analytical methods used.

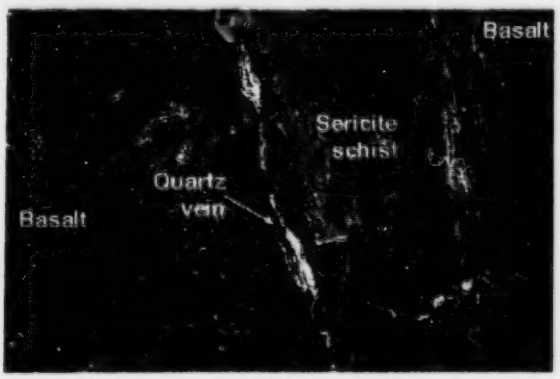


Figure 1. *Photograph of a rock face displaying a typical gold-bearing quartz-ankerite vein, with sericite schist and chlorite schist alteration envelopes, all hosted in massive basalt (Giant mine, Northwest Territories). The samples used in this study were taken from positions along lines that traverse all of these four rock types.*

ANALYTICAL APPROACH

Samples and analytical procedure

One to two specimens from each of the ten samples were cut into rectangular shapes and the electrical resistivity measured in all three directions (Scromeda et al., 2000). In addition, segment specimens from each of the ten samples were prepared for bulk density and porosity measurements (Scromeda et al., 2000). Using the results of these 3-D electrical resistivity measurements, the relationship between the electrical resistivity values and the rock texture were visually examined and analyzed (Connell et al., 2000b). Subsequent to these analysis, nine rectangular specimens were selected for scanning electron microscopy (SEM) analysis. These analyses were performed on three surfaces of each of these nine rectangular specimens, with a focus on analyzing the features that control the flow of electrical currents through the rock. Essentially, this is in an attempt to understand the electrical conductivity mechanisms of these rocks.

Method of petrophysical measurements

The petrophysical measurements that were made for this study include electrical resistivity and porosity measurements. The geo-impedance spectroscopy method was used to determine the electrical resistivity. Essentially, the complex, real and imaginary electrical resistivities were measured over a frequency range of $1–10^6$ Hz, and the results analyzed using the argon diagrams (e.g. Katsube and Walsh, 1987; Katsube and Scromeda, 1994; Katsube et al., 1996). Detailed description of the special sample preparation procedures used for these measurements are found in previous publications (e.g. Katsube et al., 1991; Katsube and Salisbury, 1991; Katsube and Scromeda, 1994). The methods used in this study to determine the bulk density and porosity are also described elsewhere (e.g. Scromeda and Katsube, 1994).

ANALYTICAL RESULTS

A summary of the ranges of porosity and electrical resistivity (ρ_r) values for the ten samples used in this study are listed in Table 1. Typical examples for the results of the electrical resistivity measurements (Connell et al., 2000b) for the ore, sericite schist, and chlorite schist are displayed in Figures 2–4. These figures display the ρ_r values for the three directions and their relationship to the visual rock texture. These figures include examples of the argon diagrams, showing how the ρ_r values are determined from the frequency spectrum of the complex electrical resistivity measurements (Scromeda et al., 2000).

Table 1. Range of electrical resistivity (ρ_r) and porosity (ϕ_E) values for the ten samples investigated in this study (Scromeda et al., 2000).

Rock type	Porosity (ϕ_E) (%)	Resistivity (ρ_r) (Ω-m)	Anisotropy (λ)
Basalt	0.4–0.42	3700–24 000	2:1–3:1
Chlorite schist	0.54–3.0	1900–13 500	6:1–7:1
Chlorite-sericite schist	0.8	1600–7500	3:1–4:1
Sericite schist	1.2–2.9	360–5900	4:1–14:1
Ore	0.56–2.6	37–3400	2:1–48:1

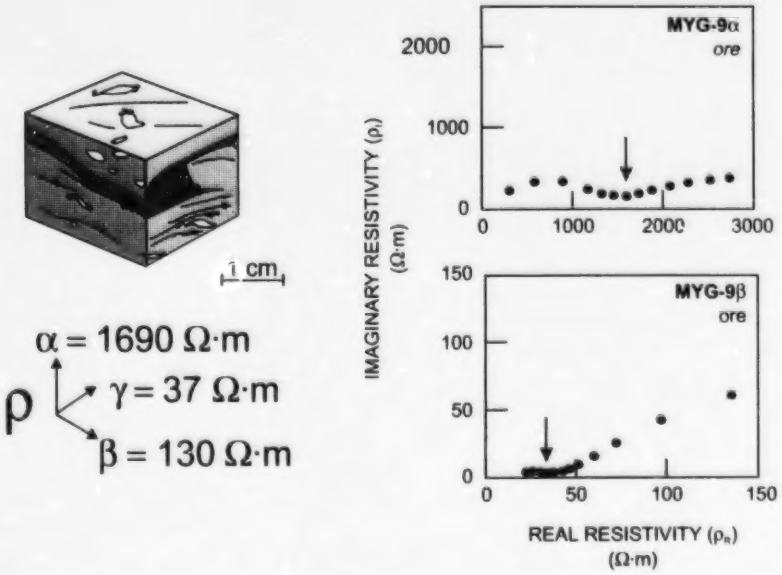


Figure 2. *Visual description of an ore sample (MYG-9) with electrical resistivity (ρ_r) values displayed for the three directions (1690, 130, and 37 Ω·m) with an electrical anisotropy (λ) of 46:1 (Connell et al., 2000b), and the argon diagrams showing how the ρ_r values were determined from the frequency spectrum of the complex electrical resistivity measurements.*

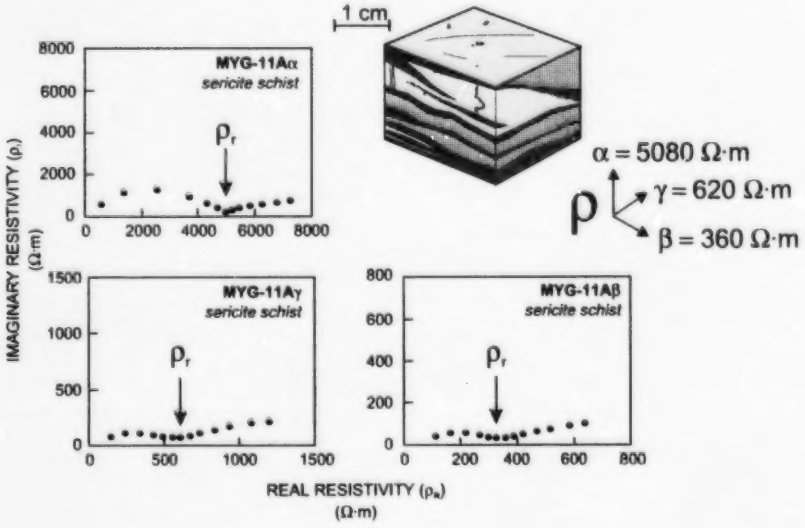


Figure 3. *Visual description of a sericite schist sample (MYG-11A) with ρ_r values displayed for the three directions (5080, 360, and 620 Ω·m) with an electrical anisotropy (λ) of 14:1 (Connell et al., 2000b), and the argon diagrams showing how the ρ_r values were determined.*

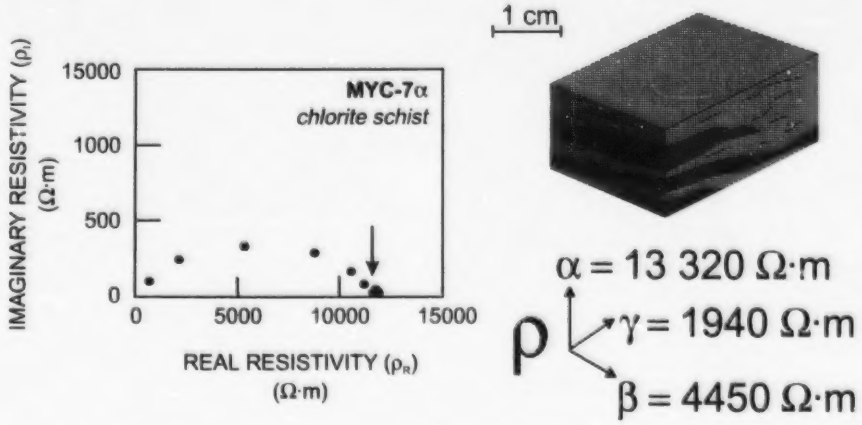


Figure 4. *Visual description of a chlorite schist sample (MYC-7) with ρ_r values displayed for the three directions (13 220, 4450, and 1940 Ω·m) with an electrical anisotropy (λ) of 7:1 (Connell et al., 2000b), and the argon diagrams showing how the ρ_r values were determined.*

The ore sample MYG-9 (Fig. 2) shows a low ρ_r value of 37 Ω·m in one direction (Connell et al., 2000b), but a high ρ_r value in another (>1600 Ω·m), resulting in a high electrical anisotropy (λ) value of >40:1. The λ values are determined by taking the ratio of the ρ_r value for the direction showing the largest value over the ρ_r value for the direction showing the smallest value. A similar example for sample MYG-11A is shown in Figure 3, representing an apparently typical mineralized sericite schist with relatively low ρ_r values (360–620 Ω·m) in two of its directions (Connell et al., 2000b), but a high ρ_r value (5080 Ω·m) in the remaining direction. This results in a relatively large λ value (14:1). Another similar example for sample MYC-7 is shown in Figure 4, representing a typical nonmineralized chlorite schist with relatively high to high ρ_r values (2000–13 000 Ω·m) for the three directions (Connell et al., 2000b), and a moderate λ value (7:1). The massive basalt samples (country rock) examined in this study show relatively high to high ρ_r values (3700–7000 Ω·m) in all three directions (Connell et al., 2000b), with the lowest ρ_r values being no less than 3700 Ω·m. Their λ values are in the range of 2:1 to 3:1. A scanning electron microscope (SEM) image, displaying sulphide-rich bands, is displayed in Figure 5 for a sericite schist sample (MYG-11A), from the Con mine.

DISCUSSION

The higher ρ_r values (2000–24 000 Ω·m) for these rock samples listed in Table 1 are at the lower end of the typical ρ_r range of values for crystalline rocks (Katsube and Mareschal, 1993). On the other hand, the lower ρ_r values (30–600 Ω·m) for the ore and mineralized rock samples examined in this study are considerably higher than the typical ρ_r range of values for these mineralized rock types, which are usually less than 10 Ω·m (e.g. Katsube et al., 1997).

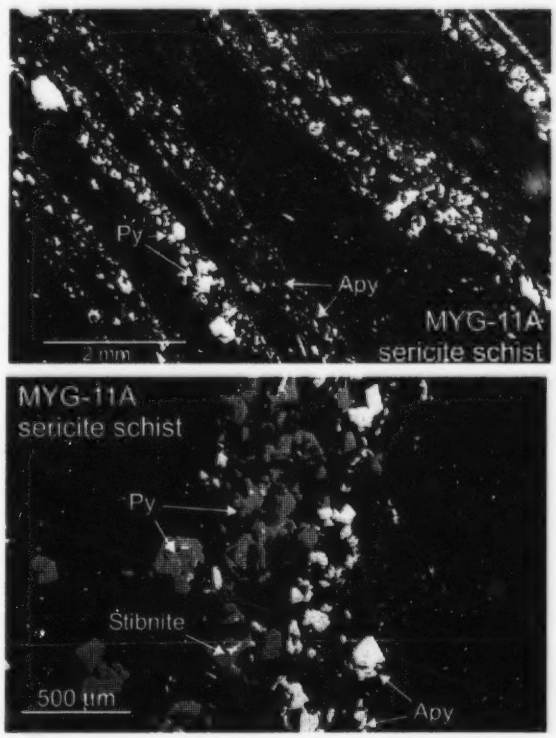
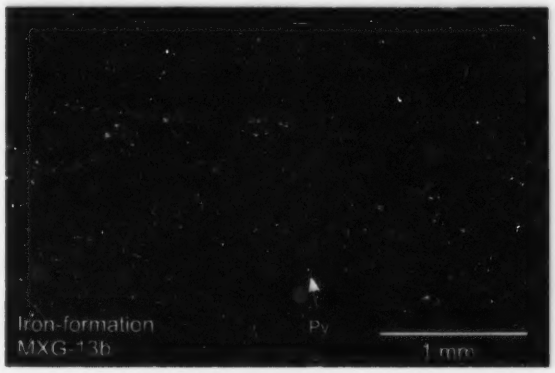


Figure 5. *Scanning electron microscopy images of the sericite schist sample (MYG-11A), from the Giant mine (Northwest Territories), displaying sulphide-rich bands, which coincide with the low electrical resistivity (ρ_r) direction of the sample. The sulphide grains are generally euhedral in shape and show little grain-to-grain interconnectivity, resulting in intermediate ρ_r values (300–600 Ω·m). Sulphide minerals include pyrite (Py), arsenopyrite (Apy), and stibnite.*

The samples examined in this study generally show moderate to strong electrical anisotropy (3:1 to 46:1), except for the relatively massive basalts (<3:1). The ore samples display ρ_r values of 37–130 Ω·m in the directions parallel to foliation or mineralization, and more than 3000 Ω·m in direction perpendicular to these features. The mineralized sericite schist display ρ_r values of 360–1000 Ω·m in the directions parallel to foliation or mineralization, and 2000–6000 Ω·m in the direction perpendicular to those features. The chlorite schist, which is generally poorly mineralized, displays ρ_r values of 2000–5000 Ω·m and more than 13 000 Ω·m in the directions parallel and perpendicular to foliation, respectively. The massive basalts display ρ_r values in the range of 7000–12 000 Ω·m, which are at the lower end for igneous crystalline rocks, as previously indicated.

The scanning electron microscope (SEM) images for the sericite schist sample (MYG-11A) displayed in Figure 5 show sulphide-rich bands, the layering of which coincide with the low electrical resistivity (ρ_r) direction of the sample (Fig. 3). This explains the lower ρ_r values (400–600 Ω·m) for that direction; however, it is important to note that these sulphide grains are generally euhedral in shape and show little grain-to-grain interconnectivity (Connell et al., 2000a). This is in contrast with the case of the chloritic iron-formation sample from Bathurst (New Brunswick) which displays deformed sulphide grains (Fig. 6) showing good grain-to-grain connectivity (Connell et al., 1999), and which results in very low ρ_r values (<10 Ω·m). It is likely that these euhedral grains, with the lack of grain-to-grain interconnectivity for sample MYG-11A is the cause of its ρ_r values to be in the intermediate range (100–1000 Ω·m), rather than the very low (<10 Ω·m) range of ρ_r values. These euhedral sulphide grain shapes are typical of the mineralized rock samples examined in this study to date. This suggests that the very low ρ_r values for the samples examined in this study, to date, are mainly a result of these euhedral grain shapes. In another study (Jones et al., 1997), an example is shown of highly concentrated sulphide minerals accumulated at the hinge of a fold (Fig. 7) which result in low ρ_r values (3–8 Ω·m) being displayed in only one direction.

The gold- and sulphide-rich sections of the ankerite-quartz vein, which display low ρ_r values, do not show evidence of good electrical continuation along the vein. On the other hand, the mineralized sections of the sericite schist which parallel the gold-bearing vein and are characterized by the intermediate ρ_r values (360–620 Ω·m), appear to be more continuous along the foliation. This continuity suggests that the sulphide-bearing sericite schist may be more easily delineated by electromagnetic (EM) methods during mineral



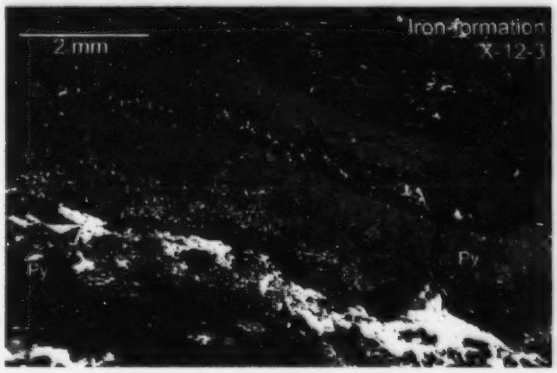


Figure 6. *Scanning electron microscopy images displaying sulphide-rich bands (Connell et al., 1999) in an iron-formation sample from Bathurst (New Brunswick), which coincide with the very low electrical resistivity (ρ_r) direction of the sample. In this case, the sulphide grains are deformed and show good grain-to-grain connectivity, resulting in low ρ_r values (<10 Ω·m); Py=pyrite.*

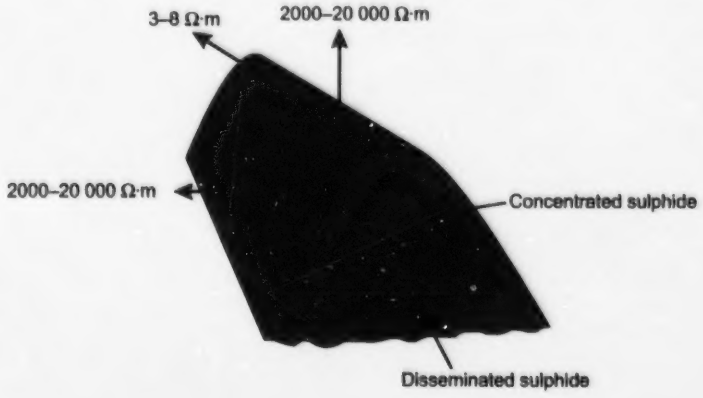


Figure 7.

Electrical model of a rock sample (northern Saskatchewan) displaying highly concentrated sulphide minerals accumulated at the hinge of a fold (Jones et al., 1997), resulting in low ρ_r values (3–8 Ω·m) in only one direction.

exploration, in contrast to the direct identification of the gold-bearing veins (discontinuous electrical conductors); however, the mineralized sericite schist and ore samples display moderate to strong electrical anisotropy, with the low-resistivity direction displaying ρ_r values within the detectable limit of electromagnetic (EM) survey systems, but the high-resistivity direction displaying ρ_r values outside the detectable limit. For this reason, whereas the low to intermediate values may be used as targets to detect mineralization by the EM survey systems, the possibility of missing the targets due to nonoptimal survey lines (Katsube et al., 1996) has to be considered.

The porosity measurements (ϕ) of the rock samples are in the range of 0.4–3.0%. It is interesting that the values for the rock samples from the Giant mine are consistently higher (1.4–3.0%) than those (0.4–1.2%) from the Con mine. The reason for this is not yet understood.

CONCLUSIONS

Some ore samples examined in this study display low electrical resistivity (ρ_r) values of 30–100 Ω·m; however, these low resistivity sections do not show evidence of being continuous conductors along the gold-bearing quartz-ankerite veins.

Where sulphide-bearing, the sericite schist that parallels the gold-bearing quartz-ankerite vein, can be characterized by intermediate ρ_r values of 300–1000 Ω·m, which are continuous along the foliation. This suggests that the intermediate ρ_r values with good continuity are better exploration targets by electromagnetic (EM) survey systems; however, the electrical anisotropy (λ) of these mineralized sericite schist samples appear to be relatively large (>10:1), implying that EM survey-line orientation is an important factor to be considered.

The ρ_r values of the nonmineralized or poorly mineralized rocks, including chlorite schist and basalt, are in the ranges of 2000–24 000 Ω·m. These are at the lower end of ρ_r values for igneous crystalline rocks.

The porosities (ϕ) of the rock samples from Giant mine have shown consistently larger values (1.4–3.0%) compared to those (0.4–1.2%) from the Con mine, for reasons not currently understood.

ACKNOWLEDGMENTS

The authors thank Bob Hauser (Chief Geologist, Con mine), Dave Arthur (mine geologist, Con mine), Tim Canam (Chief Geologist, Giant mine), and Jalil Mustafa (mine geologist, Giant mine) for their contribution to the selection of the samples. The considerable contributions made to this study by H. Falck (Government of the Northwest Territories) are acknowledged. The authors are grateful for the critical review of this paper and for the very useful suggestions made by B. Kjarsgaard (Geological Survey of Canada). This work has been supported by the EXTECH III (Exploration and TECHnology) Project.

REFERENCES

Connell, S., Katsube, T.J., Hunt, P.A., and Walker, D.
1999: Textural characteristics of rocks that display significant electrical anisotropy; *in* Current Research 1999-D; Geological Survey of Canada, p. 9–15.

Connell, S., Hunt, P.A., and Katsube, T.J.
2000a: Electrical conductivity mechanisms of sericitic schist samples from Giant and Con mine areas, Yellowknife mining district, Northwest Territories; Geological Survey of Canada, Current Research 2000-E10; (online; http://www.nrcan.gc.ca/gsc/bookstore).

Connell, S., Scromeda, N., Katsube, T.J., and Mwenifumbo, J.
2000b: Electrical resistivity characteristics of mineralized and nonmineralized rocks from Giant and Con mine areas, Northwest Territories; Geological Survey of Canada, Current Research 2000-E9; (online; http://www.nrcan.gc.ca/gsc/bookstore).

Jones, A.G., Katsube, T.J., and Schwann, P.
1997: The longest conductivity anomaly in the world explained; sulphides in fold hinges causing very high electrical anisotropy; Journal of Geomagnetics and Geoelectricity, v. 49, p. 1619–1629.

Katsube, T.J. and Mareschal, M.
1993: Petrophysical model of deep electrical conductors; graphite lining as a source and its disconnection due to uplift; Journal of Geophysical Research, v. 98, no. B5, p. 8019–8030.

Katsube, T.J. and Salisbury, M.
1991: Petrophysical characteristics of surface core samples from the Sudbury structure, Ontario; *in* Current Research, Part E; Geological Survey of Canada, Paper 91-1E, p. 265–271.

Katsube, T.J. and Scromeda, N.
1994: Physical properties of Canadian kimberlites, Somerset Island, Northwest Territories and Saskatchewan: *in* Current Research 1994-B; Geological Survey of Canada, p. 35–42.

Katsube, T.J. and Walsh, J.B.
1987: Effective aperture for fluid flow in microcracks; International Journal of Rock Mechanics and Mining Sciences & Geomechanics Abstracts, v. 24, p. 175–183.

Katsube, T.J., Best, M.E., and Mudford, B.S.
1991: Petrophysical characteristics of shales from the Scotian shelf; Geophysics, v. 56, p. 1681–1689.

Katsube, T.J., Palacky, G.J., Sangster, D.F., Galley, A.G., and Scromeda, N.
1996: Electrical properties of disseminated sulphide ore samples from Snow Lake; in EXTECH I: Multidisciplinary Approach to Massive Sulphide Research in Rusty Lake-Snow Lake Greenstone Belts, Manitoba, (ed.) G.F. Bonham-Carter, A.G. Galley, and G.E.M. Hall; Geological Survey of Canada, Bulletin 426, p. 319–329.

Katsube, T.J., Scromeda, N., Best, M.E., and Goodfellow, W.D.
1997: Electrical characteristics of mineralized and nonmineralized rocks at the Brunswick No. 12 deposit, Bathurst mining camp, New Brunswick; *in* Current Research 1997-E; Geological Survey of Canada, p. 97–107.

McDonald, D.W., Duke, A.A., and Hauser, R.L.
1993: Geological setting of the NERCO Con Mine and the relationship of gold mineralization to metamorphism, Yellowknife, N.W.T.; Exploration Mining Geology, v. 2, p. 139–154.

Scromeda, N. and Katsube, T.J.
1994: Effect of temperature on drying procedures used in porosity measurements of tight rocks; *in* Current Research 1994-E; Geological Survey of Canada, p. 283–289.

Scromeda, N., Connell, S., and Katsube, T.J.
2000: Petrophysical properties of mineralized and nonmineralized rocks from Giant and Con mine areas, Northwest Territories; Geological Survey of Canada, Current Research 2000-E8; (online; http://www.nrcan.gc.ca/gsc/bookstore).

Geological Survey of Canada Project 870057